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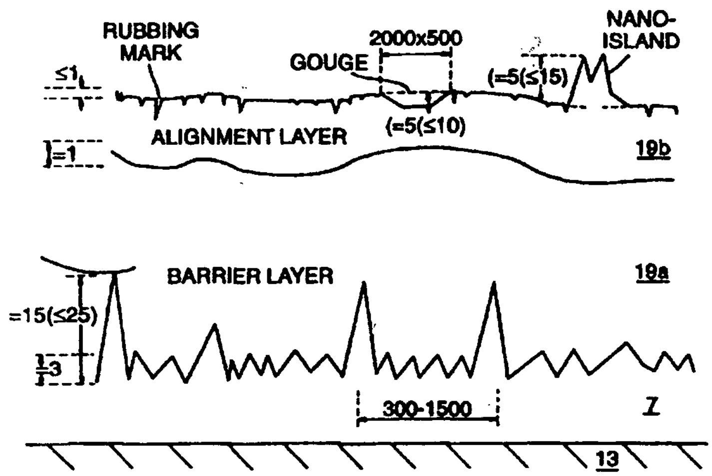

(57) Abstract

A liquid crystal device is formed by two spaced cell walls containing a layer of a liquid crystal material. Electrodes, e.g. row and column electrodes on the cell walls form a matrix of addressable pixels which collectively display information. The device is provided with a grey scale capability, that is the liquid crystal material in the device may latch to a number of states between a fully ON and a fully OFF state. To provide greyscale at least one cell wall is provided with a plurality of nucleation points whose strength varies within at least some of the display pixels. A nucleation point is a microscopic point within a cell where there is a local change in field and/or elastic strain energy variations and/or local order parameter variations to either promote or inhibit the latching process. Strength of nucleation points is the change (relative to a uniform case with no nucleation points) in threshold voltage time product required to latch at that nucleation point; strength relates to the magnitude of the effect on the voltage time product. The plurality of nucleation points may be provided by rubbing of a polymer, or by profiling a polymer layer, e.g. by a photolithographic or embossing technique, or shaping of an electrode structure surface.

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LIQUID CRYSTAL WITH GREYSCALE

This invention relates to liquid crystal device with greyscale, particularly bistable devices such as ferroelectric liquid crystal devices. bistable nematic and cholesteric devices and spatial light modulators etc.

Liquid crystal display devices are well known. They typically comprise a liquid crystal cell formed by a thin layer of a liquid crystal material held between two glass walls. These walls carry transparent electrodes which apply an electric field across the liquid crystal layer to cause a reorientation of the molecules of liquid crystal material. The liquid crystal molecules in many displays adopt one of two states of molecular arrangement. Information is displayed by areas of liquid crystal material in one state contrasting with areas in the other state. One known display is formed as a matrix of pixels or display elements produced at the intersections between column electrodes on one wall and line (or row) electrodes on the other wall. The display is often addressed in a multiplex manner by applying voltages to successive line and column electrodes.

Liquid crystal materials are of three basic types, nematic, cholesteric, and smectic each having a distinctive molecular arrangement.

The present invention particularly, but not exclusively, concerns ferroelectric smectic liquid crystal materials. Devices using this material form the surface stabilised ferroelectric liquid crystal (SSFLC) device. These devices can show bistability, i.e. the liquid crystal molecules, more correctly the molecular director, adopt one of two aligned states on switching by positive and negative voltage pulses and remain in the switched state after removal of the voltage. The two states can appear as dark (black) and light (white) areas on a display. This bistable behaviour depends upon the surface alignment properties and chirality of the material.

The bistability property, together with the fast switching speed. makes SSFLC devices suitable for large displays with a large number of pixels or display elements. Such

ferroelectric displays are described for example in:- N A Clark and S T Lagerwall. Applied Physics Letters Vol 36, No 11 pp 889-901, June, 1980; GB-2,166.256-A; us-4,367,924; US-4,563,059; patent GB-2,209,61o; R B Meyer et al, J Phys Lett 36, L69, 1975.

The term switch and switching is used to describe liquid crystal material moving between or to a particular state, e.g. ON and OFF states. For bistable devices it is more accurate to call such movement latched or latching where latching is defined as switching with bistability. In bistable devices liquid crystal molecules may move under an applied field but unless they remain (or latch) in the new state on removal of applied field, they return to an original state as with monostable devices such as conventional twisted nematic devices. Nevertheless the term switch is often used in bistable devices although the term latch is more appropriate.

For many displays two visible states only are required, i.e. an ON state and an OFF state. Examples of such displays include alpha numeric displays and line diagrams. There is now an increasing requirement for a plurality of visible states between the ON and OFF states, i.e. a plurality of different contrast levels. Such different levels are termed greyscales.

There are two known techniques for providing greyscale; these may be termed digital and analogue. The digital techniques divides into two, temporal, and spatial dither. Temporal dither involves switching a pixel to black for a fraction of a frame time and white for the remainder. Providing the switching speed is above a flicker threshold (e.g. above about 35Hz), a user's eye integrates over a period of time and sees an intermediate grey whose value depends upon the ratio of black to white time. Spatial dither involves dividing each pixel into individually switchable subpixels which may be of different size; each subpixel is sufficiently small at normal viewing distances that subpixels can not be distinguished individually. Both temporal and spatial dither techniques can be combined to increase the number of greyscale levels in a display; see EP9000942, 0453033, W Hartmann. J van Haaren. EP-0,214.857. EP-261,901.

Analogue greyscale may be described as partly switching a material to a condition lying between fully ON and OFF. A characteristic of SSFLCs is that they switch on receipt of a pulse of suitable voltage amplitude and length of time of application, i.e. pulse width, termed a voltage time product V.t. Additionally when a voltage is applied to electrodes, not all molecules move at the same time. As a result, some time after a voltage has been applied, small areas or volume of material within a pixel area will be switched to ON whilst other small areas or volumes will remain OFF. The relative amounts of ON and OFF is integrated by eye to show different amounts of darkness or greyscale. This variation within the liquid crystal layer may be termed partial switching. By controlling the amount of partial switching within a pixel, varying degrees of greyscale may be obtained. Unfortunately no reliable method existed to control partial switching over complete displays.

Previously, in order to obtain greyscale in a FELCD, it was necessary to use digital techniques because of problems in obtaining uniform greyscale using partial switching.

According to this invention the problem of control of partial switching is solved by controlling the strength of nucleation points within a liquid crystal cell. Nucleation points are microscopic points within a cell where there is a local change in field and or elastic strain energy variations and or local order parameter variations to either promote or inhibit the latching process. Strength of nucleation points is the change (relative to a uniform case with no nucleation points) in threshold voltage time product required to latch at that nucleation point; strength relates to the magnetude of the effect on the voltage time product.

According to this invention greyscale is provided by a variable strength of nucleation points within a pixel area of a display, such a variation increases the partial switch region on a voltage time product curve..

According to this invention a liquid crystal device cell comprises:

two cell walls spaced apart to contain a layer of a liquid crystal material,

electrode structures on both cell walls arranged to provide a plurality of separately addressable pixels;

a surface alignment treatment on both cell walls to provide a surface alignment to liquid crystal molecules;

CHARACTERISED BY

a plurality of nucleation points on the surface of at least one wall, the nucleation points being of a variable strength within at least some of the pixels.

The device may also include means for distinguishing between two switched (latched) states of the liquid crystal material.

The nucleation points may be provided by small localised surface features such as spheres or projections or spikes or indents or islands on the alignment treatment. The spheres may be of metallic, semi insulating, semi conducting, or insulating material. The alignment treatment may be a rubbing of the cell wall, a rubbing of a polymer layer on the walls, an obliquely evaporated alignment layer, a grating structure formed in a layer of a photoresist material, a grating structure embossed in a plastic layer, a photo-aligning layers, or other topological alignment structure.

The variation in strength of nucleation point may be achieved in three ways:
(a) varying the dimensions of localised features such as small indents in or small spikes or bumps on an insulating layer and or electrodes within the area of a pixel.
(b) varying the density of the localised features;

(c) a mixture of (a) and (b).

The variation in strength of nucleation points may be achieved by photolithographic techniques, or mechanical damage e.g. rubbing of a surface by a cloth, or rolling by a spiked roller, or embossing.

Within a pixel area, the density of nucleation points may vary from a few points per $10\mu m^2$ to numerous points per $10\mu m^2$. For example the nucleation points may vary on average between one per $10\mu m^2$ to a thousand or more per $10\mu m^2$, density being measured as average distance between points. The density may vary uniformly or in a non-linear manner across a pixel, or it may vary differently along an alignment direction to that orthogonal to the alignment direction. The dimension of the localised features may also vary in a similar manner.

Additionally the electrodes may be arranged to provide sub-pixellation. i.e. a pixel area is divided into a plurality of sub pixels of similar or different areas. The variation of nucleation points may be the same on adjacent pixels or sub pixels, or may vary on adjacent pixels or sub pixels. Areas of the cell between electrodes may have a different density of nucleation points to that within the pixel areas. e.g. the inter pixel gaps may have few nucleation points.

The variation in strength of nucleation points may be arranged to be the same or different in different areas of a large display so that overall uniformity of greyscale is obtained. For example the strength may be different in different areas to compensate for variations in voltage over long electrodes.

The liquid crystal material may be a chiral smectic material, e.g. a chiral smectic C* and the device is a surface stabilised ferroelectric liquid crystal device, an electroclinic device with a smectic A material, an antiferroelectric device, a ferrielectric device, or may be a nematic, or long pitch cholesteric material with or without an amount of a dye and the device is a nematic type device.

During the switching of the liquid crystal within an FLCD from one state to the other, not all of the molecules or directors change state simultaneously. The present invention exploits the fact that certain features within a cell act as nucleation points in the switching process and the liquid crystal at these nucleation points will switch at a lower applied voltage than that of the surrounding liquid crystal material. Furthermore, the strength of these nucleation points may be varied so that different small areas within a pixel will start to switch at different voltage time products.

A number of mechanisms may be responsible for this effect: elastic deformations and variations in the effective field applied as a consequence of the switching voltage; nucleation mechanisms, e.g. disruption of the smectic layer structure giving a localised change in the elastic strain energy, e.g. local variation of electric field such as by dielectric refraction effects or combination of these; and also effective local thickness change of the cell. If a switching voltage of sufficient magnitude is applied for a very short time then only the liquid crystal in the immediate vicinity of the nucleation points may change state and small latched domains will result. If the switching voltage is applied for a longer duration then these domains may grow, or at different values of voltage and time domains of different size may be spontaneously created. When these isolated domains within a pixel where the liquid crystal has changed state all meet one another, the pixel will have fully changed state.

While the invention is described in relation to a display device, it is equally applicable to shutter devices used, for example, in spatial light modulators, in laser printers and plain paper facsimile machines.

Brief description of drawings.

One form of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:-

Figures 1a. 1b, are plan and section views of a liquid crystal display device;

Figure 2a shows a graph of switching time against applied voltage for a typical ferroelectric liquid crystal device (FLCD),

Figure 2b shows a graph of optical transmission against voltage for a given pulse width applied to a typical FLCD;

Figure 3 shows a diagrammatic view of a portion of the wall of a FCLD,

Figure 4 shows the result of an atomic force microscopy (AFM) analysis of a portion of rubbed polyimide alignment layer for a FLCD,

Figure 5 shows the result of AFM analysis of a portion of rubbed polyimide alignment layer to a larger scale than that shown in figure 4,

Figure 6 shows the result of AFM analysis of a portion of nylon material;

Figure 7 shows the result of AFM analysis of a portion of nylon material to a larger scale than that shown in figure 6,

Figure 8 shows the result of AFM analysis of a portion of nylon alignment layer for use in a FLCD;

Figure 9 shows a perspective view of AFM analysis of a portion of polyimide alignment layer,

Figure 10 shows a perspective view of AFM analysis of a portion of nylon material;

Figure 11 shows a graph of switching time τ against applied voltage for a FLCD having a polyimide alignment layer,

Figure 12 shows a graph of switching time τ against applied voltage for a FLCD having a nylon alignment layer, and

Figure 13 shows manufacturing steps of an FLCD.

The cell 1 shown in Figures 1, 2 comprises two glass walls, 2, 3, spaced about 0.5-6μm apart by a spacer ring 4 and/or distributed spacers. Electrode structures 5, 6 of transparent indium tin oxide are formed on the inner face of both walls. These electrodes may be of conventional line (x) and column (y) shape, seven segment, or an r-θ display. A layer 7 of liquid crystal material is contained between the walls 2, 3 and spacer ring 4. Polarisers 8, 9 are arranged in front of and behind the cell 1. The alignment of the optical axis of the polarisers 8, 9 are arranged to maximise contrast and brightness of the display; i.e. approximately crossed polarisers with one optical

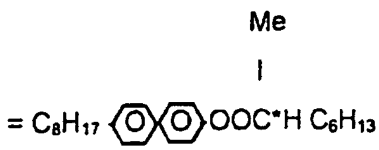
axis along one switched molecular direction. A d.c. voltage source 10 supplies power through control logic 11 to driver circuits 12, 13 connected to the electrode structures 5, 6, by wire leads 14, 15.

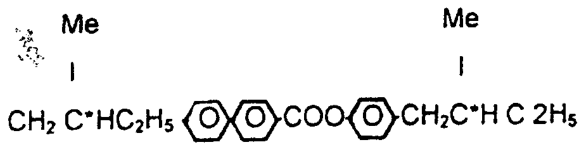
The device may operate in a transmissive or reflective mode. In the former light passing through the device e.g. from a tungsten bulb 16 is selectively transmitted or blocked to form the desired display. In the reflective mode a mirror 17 is placed behind the second polariser 9 to reflect ambient light back through the cell 1 and two polarisers. By making the mirror 17 partly reflecting the device may be operated both in a transmissive and reflective mode with one or two polarisers.

Prior to assembly the walls 2, 3 are surface treated e.g. by spinning on a thin layer 18, 19 of a polymer such as a polyamide or polyimide or a nylon, drying and where appropriate curing; then buffing with a soft cloth (e.g. rayon) in a single direction Rl, R2. This known treatment provides a surface alignment for liquid crystal molecules. The molecules (as measured in the nematic phase) align themselves along the rubbing direction Rl, R2, and at an angle of about 0° to 15° to the surface depending upon the polymer used and its subsequent treatment; see article by S Kuniyasu et al, Japanese J of Applied Physics vol 27. NO 5, May 1988, pp827-829.

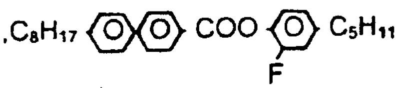
Alternatively surface alignment may be provided by the known process of obliquely evaporating e.g.. silicon monoxide onto the cell walls or by grating structures. Grating structures are described for example in WO95/22075, and may be formed photolithographically, with or without polarised light, or by embossing of a plastics layer. Instead of profiling an insulating layer, alignment may be provided by profiling the electrodes to give both alignment and control of nucleation points. The electrodes may be formed directly on the cell walls or coated onto profile walls of the cell or profiled plastic layers.

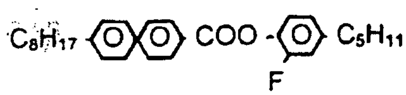
Suitable liquid crystal materials include catalogue references SCE 8, ZLI-5014-000, available from Merck Ltd, those listed in PCT/GB88/0I004. WO 89/05025. and:-
19.6% CM8 (49% CCI + 51% CC4) + 80.4% H_1

CC1 = 

CC4 = 

H, = M1 + M2+ M3 (1 : 1 : 1)

M1 = 

M2 = 

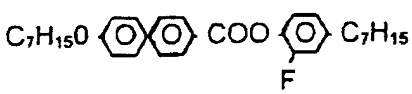
M3 = 

Figure 2a shows a graph of switching time τ against applied voltage V for a typical ferroelectric device. As previously noted a ferroelectric material switches on receiving a voltage time product of suitable value. Thus for a given switching curve a voltage time product above the curve results in switching whilst a voltage time product value below the curve will not result in switching.

Additionally, as described in US-5,497,173, US-5,398,042, EP-0542804, PCT/GB91/01263, the shape and position of the switching curve depends upon the shape of the applied addressing waveforms. These double switching curves allow greater discrimination between pixels required to switch and those that are not required to switch when a display is multiplex addressed. Pixels required to switch are supplied with a waveform of a shape where the lower curve applies whilst other pixels not required to switch receive a waveform of a shape where the upper curve applies. Both sets of pixels receive a voltage time product that may be above the lower curve, i.e. in the shaded area, but only those pixels receiving the switching shape of waveform will switch.

The lower solid curve (100%) gives the minimum time and voltage product required to latch all of the molecules (more correctly the directors) within a pixel into the other state. The broken line (0%) beneath it gives the time and voltage product at which the directors in a pixel will just start to latch. The following discussion will concentrate on the partial switching region of the switching curve, i.e. the portion between the 100% and 0% curves. The partial switching region of the non-switching curve NS may, however, be controlled in an analogous manner.

In order to drive a FLCD to provide a grey scale output, the region of the switching characteristic between the 0% and the 100% curves is utilised. In the present invention, the width of this region is controlled to provide the desired number of grey scales. For a device utilising grey scale the width of this partial switching region should be wide. This contrasts with a device without grey scale where the device is required to switch

cleanly between fully ON and OFF states; in this situation the width of the partial switching region can be made as narrow as possible.

For a perfectly uniform cell, all molecules would commence latching at the same voltage time product. However, as explained below surface irregularities affect latching. Localised imperfections provide nucleation points where molecules commence latching at lower voltage time products than at other positions. What is required for a wide partial switching region is a variation in the voltage time product latching value at different parts of a pixel.

This is achieved by varying the surface profile at the liquid crystal interface. The surface of an insulating alignment layer may be profiled with indents or holes of varying depths. Within these indents liquid crystal molecules will switch at a different voltage time product than at the upper part of the alignment layer. For example with some materials, the deeper the indent the higher the electric field at its bottom, and therefore the lower the switching voltage time product at this indent. Conversely, the higher a bump on the alignment surface, the lower the electric field, and the higher the switching voltage time product. Therefore by varying the depths and or number of indents and bumps per unit area (their density) the width of the partial switching region can be varied.

The effect of increasing the width of the partial switching region is shown in figure 2b. The figure 2b assumes a single pulse width (time of applied voltage) and shows variation of light transmission against applied voltage. An idealised switching curve for a device without greyscale is shown in continuous line. At a certain voltage all molecules switch states. In practice this does not occur and switching occurs over a relatively narrow voltage range shown in chain dotted lines. If the partial switching region is made wide, then some parts of the pixel will switch at a voltage below the normal value whilst others will require a higher voltage to cause switching. By varying the strength of nucleation points over a pixel, the slope and shape of the transmission voltage curve can be made lower as shown in dotted line.

Other shapes are possible; the illustrated curve could be shifted either to the left or right, or the curve may be made non-linear etc. The shape of the dotted switching curve shows that it is possible to obtain different transmission levels, i.e. greyscales, with different voltages. A similar curve is obtained for a fixed voltage and variable pulse width (address time).

Figures 3 to 10 show the effects of different alignment treatments on spacing etc. of nucleation points on a cell wall.

Figure 3 shows a diagrammatic representation of a portion of the cell in Figure 1b to an enlarged scale. The figure shows a transparent wall 13 and an electrode layer 7 thereon. Above the electrode 7 is a barrier layer 19a intended to isolate the electrode 6 from the liquid crystal 7 and above the barrier layer 19a is an alignment layer 19b. The barrier layer 19a and the alignment layer 19b may comprise a single layer 19. The alignment layer 19b in this example comprises rubbed polyimide, for example PI32 (Ciba Geigy). All of the approximate dimensions on the figure are in nanometres. Two observations can be made quickly; the electrode layer 7 is very uneven and the alignment layer 19, while being less uneven than the electrode layer 7 still exhibits some considerable discontinuities.

These discontinuities have a particular effect on the switching performance of the FLCD. A pixel will typically measure 300μm by 100μm and a FLCD will typically be 1.5 to 4μm in thickness. It will be appreciated by considering figure 3 that certain pixels will have noticeable discontinuities within their boundary such as the rubbing marks and nano-islands shown while other pixels will have rather fewer and smaller discontinuities. These discontinuities cause elastic deformations in the liquid crystal device which permits some areas of the liquid crystal device to change state before other areas, thus providing nucleation points. The roughness of the underlying ITO electrode layer will lead to local variations in the electric field and therefore play an important role in the width of the partial switching region.

Where it is desired that the partial switching region be narrow (not as in the present invention), electrode layer should have uniform roughness. Surface roughness increases with the thickness of the electrode layer because it is provided by sputtering. However, this will also increase the size and the density of large spikes. By increasing the length of the sputtering process and polishing the electrode layer to remove these spikes, a more uniformly rough surface is provided. An added benefit of an electrode layer provided in this manner is that a shallower barrier layer may be provided which will reduce the voltage drop across such a layer.

It can be understood from figure 3 that while the discontinuities arising from the alignment layer and the electrode layer provide potential nucleation points for the switching of the liquid crystal, these discontinuities are so widely spaced and randomly located and dimensioned that there is poor control over the switching performance of the device.

Figure 4 shows atomic force microscopy (AFM) results for a rubbed polyimide alignment layer over an area of 5 μm by 5 μm. AFM measures the topology of a surface, in other words the degree of roughness. The degree of roughness is depicted by a grey scale and the key is shown on the right hand side of the figure. It can be seen that there is only around 1nm of RMS roughness over a distance of 1μm. In addition, a pair of striations are shown running the length of the AFM plot. These are the rubbing marks which are a consequence of the polyimide layer being rubbed to align the directors of the liquid crystal material. The rubbing marks are widely spaced and are typically several microns or tens of microns apart. While some areas of the layer are comparatively rough and would be expected to provide effective nucleation points for changing the state of a liquid crystal in use, large areas of the AFM result show very little variation in roughness. This means that switching domains would have to grow over larger distances in order to meet one another, increasing the size of the partial switching region.

Figure 5 shows AFM results for a 1μm square section of a rubbed polyimide layer on a larger scale than those shown in figure 4. Parts of the rubbing marks are again visible in this figure. It can be seen that the rubbing marks provide a high density and reasonably uniform distribution of nucleation points. However, over the remainder of the figure the distribution of such points is extremely varied with some clusters very close together but large areas with no significant topological variation. In addition, most of the potential nucleation points are also small in area.

Figure 6 shows AFM results for a 5μm square sample of nylon 6,6 which has not been subjected to a rubbing step. The scale of the AFM in this figure is somewhat larger than that of figures 4 and 5 and is shown at the right of the figure. The area of nylon analysed is equal to that of polyimide whose results are shown in figure 4. The roughness is typically 5nm over a 1μm distance. By comparison with figure 4 it will be appreciated that the potential nucleation points for this material are higher in number and larger (the material is more rough) and also that the distribution of such points is substantially more even (the roughness is more consistent). It will be shown later with reference to figures 11 and 12 that this has a profound effect on the partial switching region of the device.

Figure 7 shows AFM results for the nylon 6,6 sample over the same area as that used in figure 5. It can be seen from this figure that the potential nucleation points are not only more consistently spaced apart from one another but they are generally of a larger size. It can be seen that the scale of this figure differs slightly from that of figure 6 but the roughness of the surface of the material is still approximately double that of the rubbed polyimide as well as being more uniform.

We now consider whether the regular topology and potential nucleation point properties of the nylon layer are maintained if the layer is rubbed to provide an alignment layer. Figure 8 shows AFM results for a sample of rubbed nylon 6,6 over the same area as those shown in figures 4 and 6 but having a different scale. This larger scale is required to cover the combined effects of the intrinsic roughness of the

nylon and the roughness induced by the rubbing process. Six rubbing lines are visible in the figure running substantially from the top to the bottom of the figure. While the density of potential nucleation points is increased along the rubbing marks, the density of such points away from the rubbing marks is still substantial and evenly distributed.

Figures 9 and 10 respectively show AFM results in a perspective view for a sample of rubbed polyimide and unrubbed nylon 6,6 over an area of 1μm square. Again the topology of the nylon shows not only a greater consistency of roughness but also a greater amplitude of the roughness. Figure 10 shows probably more clearly than the plan-view AFM results the consistent periodic structure of nylon which will be shown to provide a uniform density of nucleation points.

From these results it would be expected that the partial switching region of a FLCD using an alignment layer of nylon would exhibit a smaller partial switching region than one using an alignment layer of rubbed polyimide. Figures 11 and 12 show the results of such a comparative test.

Figure 11 shows a series of curves which are equivalent to the curve S sketched in figure 1. The voltage of the applied signal is shown along the X axis and the duration of the signal along the Y axis. Instead of using a measurement of 0% and 100% of optical transmission to provide the results a common alternative of 10% and 90% of optical transmission is used in these examples. Three sets of curves are shown in the figure which correspond to different levels of AC stabilisation. AC stabilisation is a technique well known in the use of FLCDs in which an AC voltage of moderate amplitude is applied to each of the pixels of the device constantly when it is not desired to change the state of the pixel. The reasons behind this, and the benefits of so

doing are well known to those skilled in the art and do not directly concern the present invention. In figure 11, the curves represent (in descending order):

1)	Vac=7.5V	90% switched
2)	Vac=7.5V	10% switched
3)	Vac=5.0V	90% switched
4)	Vac=5.0V	10% switched
5)	Vac=0V	90% switched
6)	Vac=0V	10% switched

The switching process was observed microscopically and the device with a polyimide aligning layer had few switching nucleation points. The 10% of optical transmission switching level corresponded with just a few domains of switched liquid crystal.

Figure 12 represents corresponding results for a FLCD using a rubbed nylon 6,6 alignment layer, the curves in this figure correspond with those identified above (also in descending order). By comparison of the curves shown in figures 11 and 12, it can be seen that the partial switching region of the FLCD using the nylon alignment layer is significantly narrower than that of the rubbed polyimide layer.

From this experimental switching data taken on nylon and polyimide devices filled with SCE8 it is seen that a typical polyimide cell showed a Δt of 5.9μs at a t_{min} of 42.4μs (Δt is defined as the time difference between the 10% switching and 90% optical transmission switching points). The corresponding nylon cell showed a Δt of 2.9μs at a t_{min} of 46.5μs. Hence the partial switching region of the nylon cell is roughly half that of the polyimide cell. Thus a uniform, high density of nucleation

points in the alignment layer provides a partial switching region of reduced width and vice versa. In contrast to the microscopic examination of the switching process in the device having a polyimide alignment layer, the 10% level of optical transmission of the nylon-aligned device was found to correspond with a large number of relatively small switched domains.

As alternatives to selection of a suitable material to form an alignment layer, the present invention further provides for a nucleation site layer or layers to be processed to increase or decrease their nucleation point density prior to inclusion in a ferroelectric liquid crystal device. The invention further provides that the roughness can be electrical in nature rather than partly or purely topological. One way of achieving this is for the electrode layer to be arranged to provide nucleation points by increasing the local electric field. Further, extra material may be used to provide nucleation points in either of the alignment layer or the electrode layer.

Figure 13 shows diagrams corresponding to two steps in the manufacture of one example of a liquid crystal device in accordance with the present invention. Figure 13(a) shows a production step to be performed after the substrate has been provided with an electrode layer and a barrier layer. The substrate 12 is arranged to rotate at high speed while a solvent and monomer mixture is spun-down onto the surface thereof. This process is already known to be used to provide an alignment layer. Once the layer is spun down the monomer is polymerised using a known technique, for example ultraviolet irradiation. Then a mask M of any suitable material is provided on top of the layer and a number of photo-defined holes (or bumps) are provided by photolithography P. Alternatively, the holes (or bumps) may be provided by direct laser lithography.

After development, the surface would then contain small photoresist spots separated by regions of the original polymer. Rubbing to provide the alignment for the liquid crystal material is then carried out after applying the dots to the surface although these steps may be reversed. Current patterning techniques would allow dots to be defined

with diameters of less than 300nm and technologies are becoming available which will allow 100nm features to be defined. Varying the depths (heights) or densities of the features in a controlled manner allows the partial switching region to be controlled spatially either from pixel to pixel or within a pixel.

This second step shown in figure 13 may be replaced by other treatments such as plasma etching, acid etching or exposure to a combination of ozone and ultraviolet light. These techniques, which are well known and will not be discussed further here, are suitable for controlling the overall density of nucleation points on the alignment layer but are not capable of providing the selectivity required for differing densities of nucleation points (whether from pixel to pixel or within a pixel).

In an aspect of the invention alternative to treatment of the alignment layer itself, another technique is to add further material to provide discontinuities in the surface thereof. One such material which has been found to be effective is gold beads having a nominal diameter of 6nm. These beads provide a degree of roughness to the surface of the alignment layer that is comparable to that provided by the nylon alignment layer discussed above. In addition, the density of the beads can be controlled by varying the number applied to a given area of the alignment layer. Another material that has been found to be successful are .5μm plastics beads. While these beads extend approximately one third of the distance across the device they have not been found to cause adverse effects in terms of the normal operation of the device. Another benefit of using added material in the alignment layer of a FLCD is that the process of adding the material disrupts the alignment layer itself, thus generating further nucleation points.

The addition of metallic spheres may also be applied to the electrode layer although the size required will be greater than that used in the alignment layer. Alternatively, the sputtering process by which the electrode layer is traditionally produced may be carried out for an extended period to provide a significantly rougher electrode layer.

This does tend to result in a number of particular peaks which are too high relative to the remainder of the layer. These peaks are then removed by polishing the electrode layer before the barrier layer and/or alignment are added to the wall structure.

While the above described techniques are concerned with increasing the nucleation point density, it is also required to reduce this density in some circumstances to provide a partial switching region that is wider than would otherwise be the case. One suitable technique is ion beam milling and this may be applied to an alignment layer before or after it is rubbed to provide the alignment for the liquid crystal.

Claims.

A liquid crystal device cell comprising:

two cell walls spaced apart to contain a layer of a liquid crystal material,

a first set of electrode structures on one cell wall and a second set of electrode structure on the both cell wall arranged to provide a plurality of separately addressable pixels;

a surface alignment treatment on both cell walls to provide a surface alignment to liquid crystal molecules;

CHARACTERISED BY

a plurality of nucleation points on the surface of at least one wall, the nucleation points being of a variable strength within at least some of the pixels.

2. The device of claim 1 wherein the variation of nucleation points is a variation in nucleation point surface dimensions within a pixel.

3. The device of claim 1 wherein the variation of nucleation points is a variation in nucleation point density within a pixel.

4. The device of claim 1 wherein the variation of nucleation point strength is different in different directions within a pixel.

5. The device of claim 1 wherein at least some of the pixels are subpixellated.

6. The device of claim 5 wherein the subpixel are of different sizes within each pixel.

7. The device of claim 3 wherein the density of nucleation points varies from a few points per $10\mu m^2$ to numerous points per $10\mu m^2$.

8. The device of claim 3 wherein the density of nucleation points varies within the range of about one to about 100 per $10\mu m^2$ or more.

9. The device of claim 1 wherein the strength of nucleation points is different in gaps between pixels to that at pixels.

10. The device of claim 1 wherein both cell walls carry a plurality of nucleation points on their surface, the nucleation points being of a variable strength within at least some of the pixels, and the same or different variation on both cell walls.

11. The device of claim 1 wherein the variation in nucleation point strength at each pixel is substantially uniform over a complete device

12. The device of claim 1 wherein the variation in nucleation point strength at each pixel is varied over a complete device so that overall uniformity of greyscale is obtained.

13. The device of claim 1 wherein the liquid crystal material is a chiral smectic or a nematic liquid crystal material.

14. The device of claim 1 and further including means for distinguishing between the two switched states of the device.

15. The device of claim 1 wherein the two sets of electrodes are formed as row and column strip electrodes and the pixels are arranged in an x,y matrix format.

16. The device of claim 1 and further including means for applying addressing waveforms to the two sets of electrodes in a multiplex addressed manner.

17. The device of claim 1 wherein the plurality of nucleation points is provided on a rubbed polymer layer, or an etched polymer layer,

18. The device of claim 1 wherein the plurality of nucleation points is provided by a grating surface.

19. The device of claim 1 wherein the plurality of nucleation points is provided by an embossed surface

20. The device of claim 1 wherein the plurality of nucleation points is provided by a plurality of small spheres on an aligning layer.

21. The device of claim 20 wherein the spheres are of metallic, semi insulating, semi conducting, or insulating material of diameter less than 0.1μm or less.

22. The device of claim 20 wherein the spheres are of gold or plastics material of diameter less than 0.1μm or less.

Fig.1a.

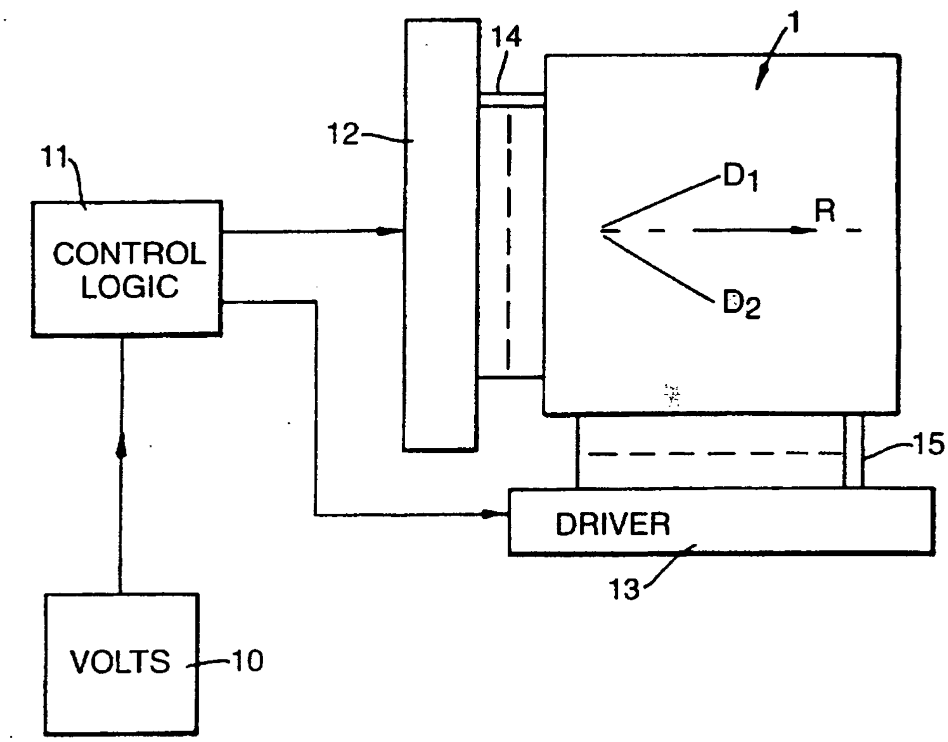
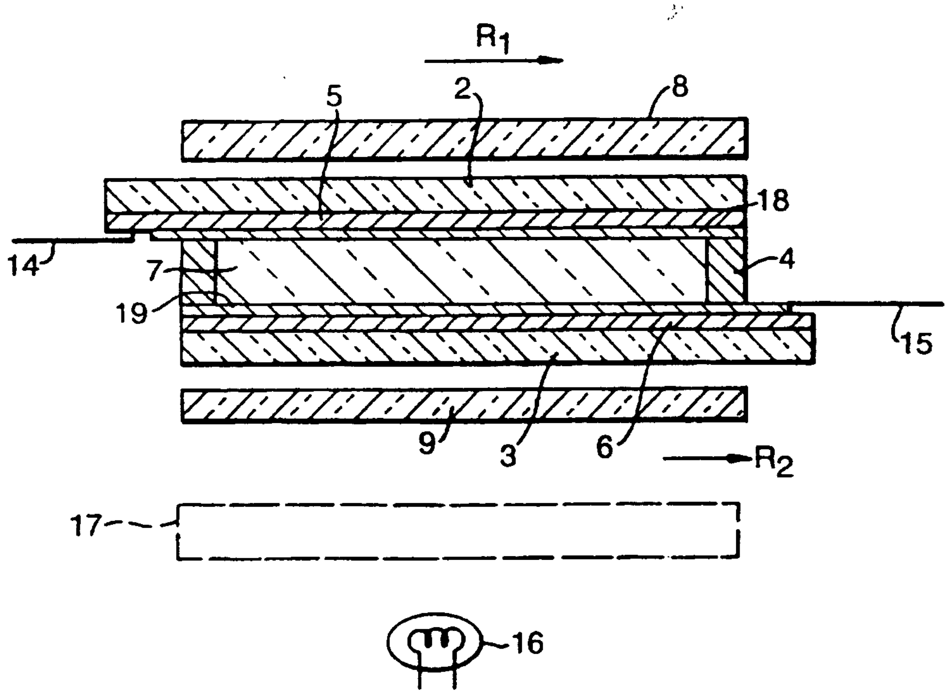

1
14
12
11
CONTROL
LOGIC
D1
R
D2
15
DRIVER
13
VOLTS
10

Fig.1b.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8
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14
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4
19
15
9
3
6
R2
17
16

Fig.2a.

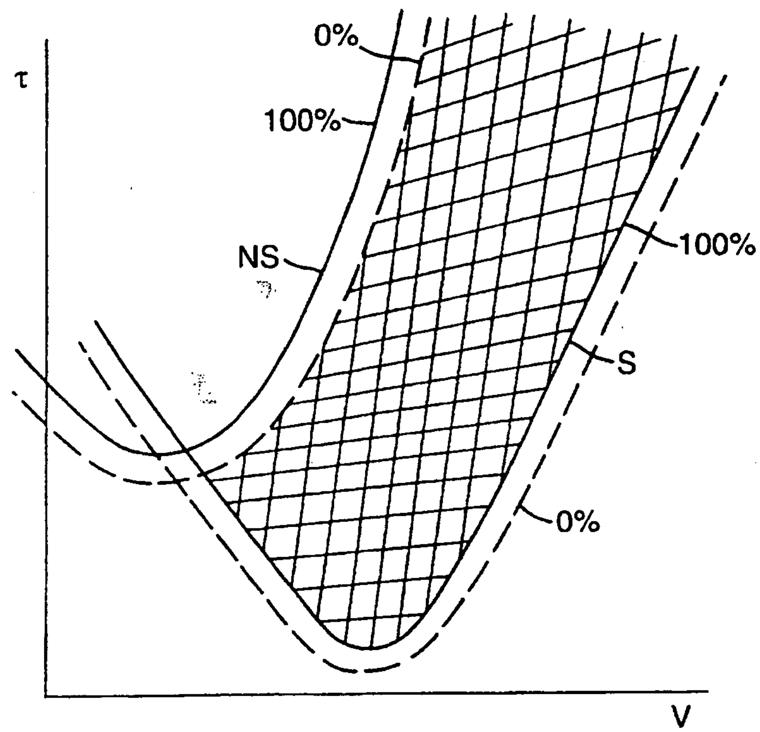


Fig.2b.

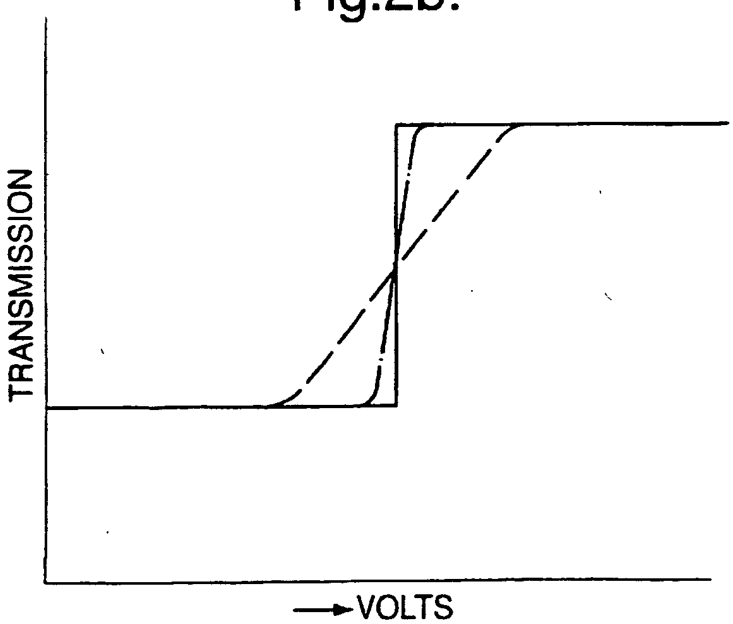
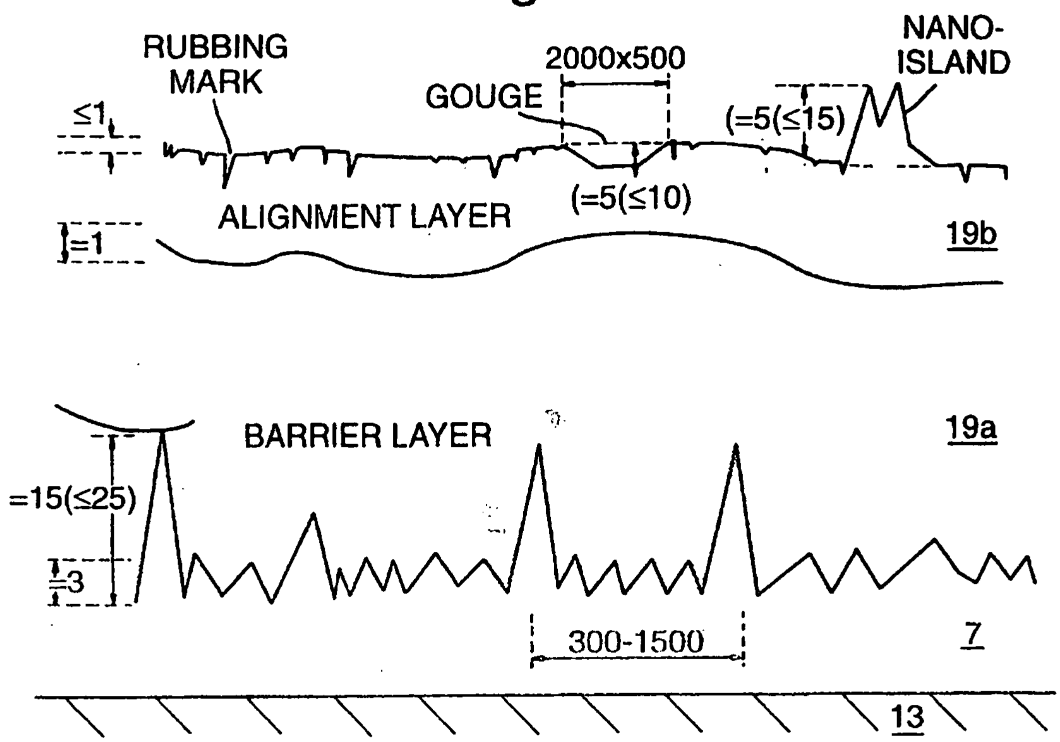


Fig.3.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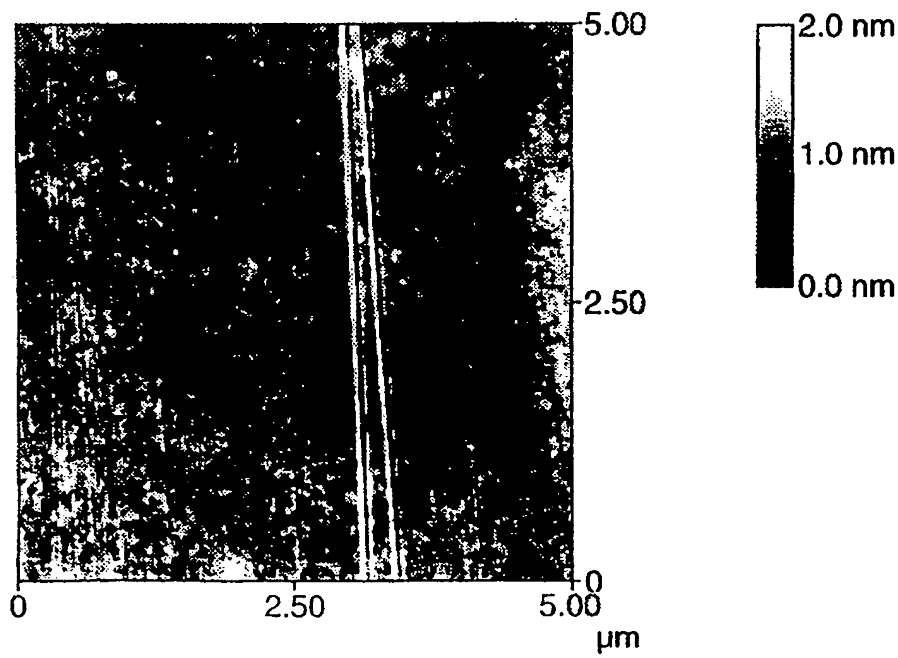
NANO-ISLAND
GOUGE
≤1
(=5(≤15)
(=5(≤10)
ALIGNMENT LAYER
=1
19b
BARRIER LAYER
19a
=15(≤25)
=3
300-1500
7
13

Fig.4.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0
2.50
5.00
μm
2.0 nm
1.0 nm
0.0 nm

Fig.5.

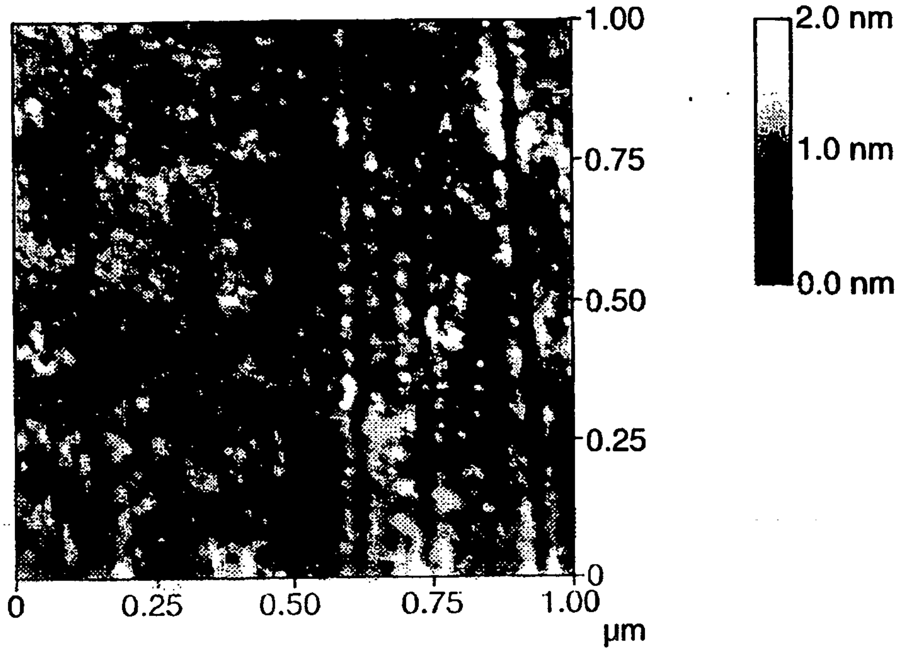
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Fig.6.

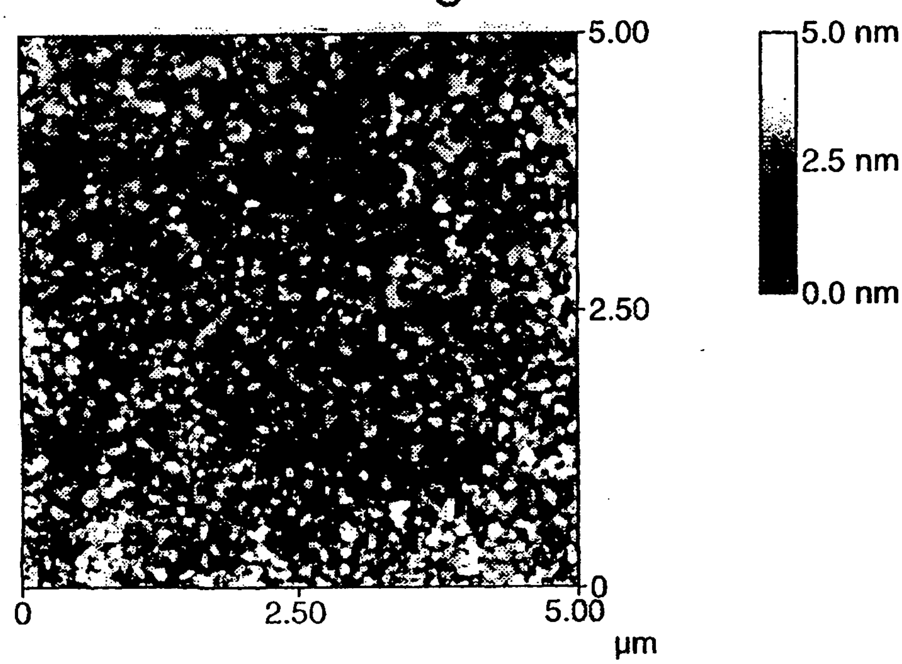
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Fig.7.

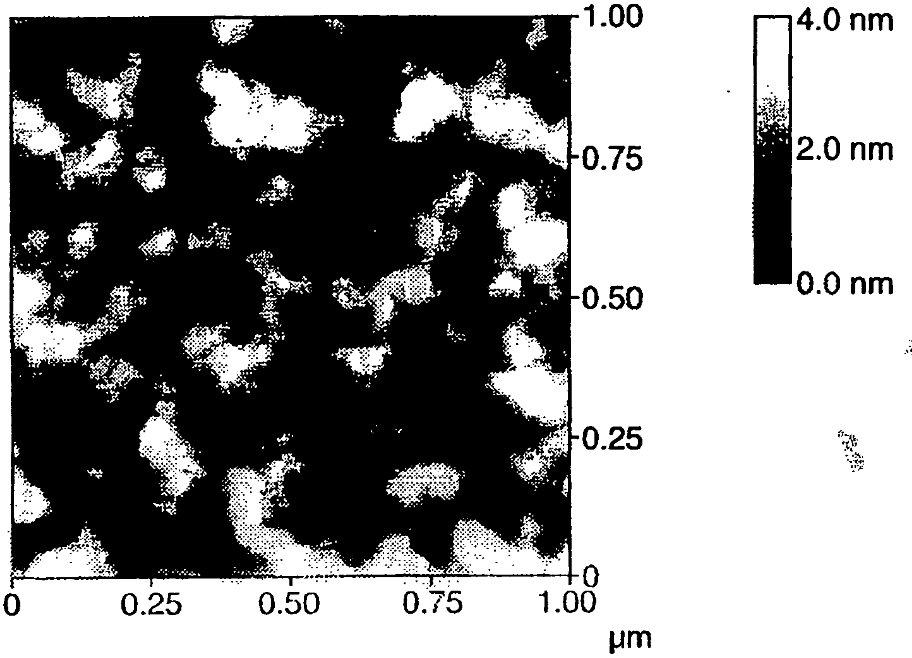
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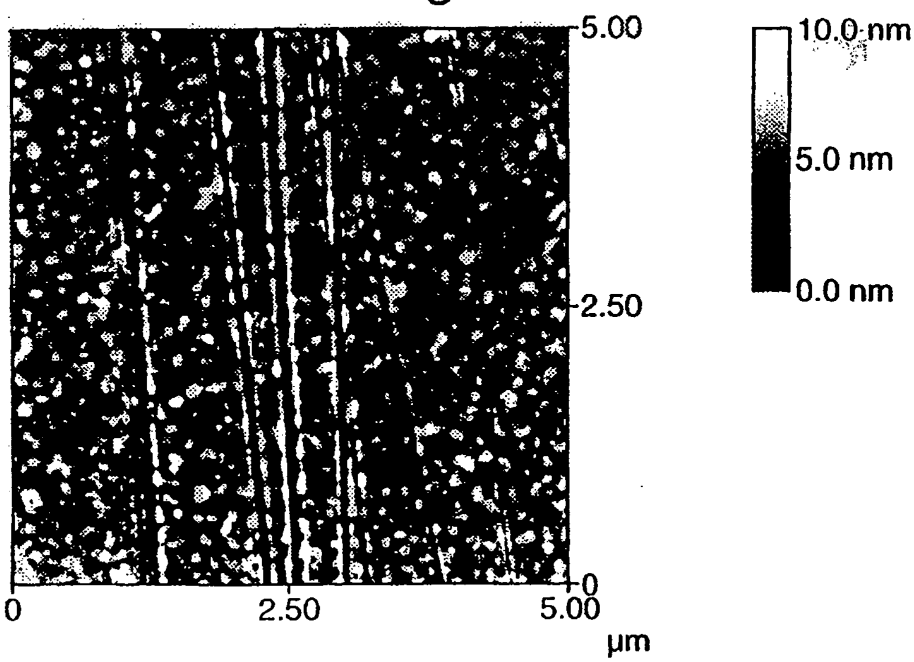
Fig.8.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μm
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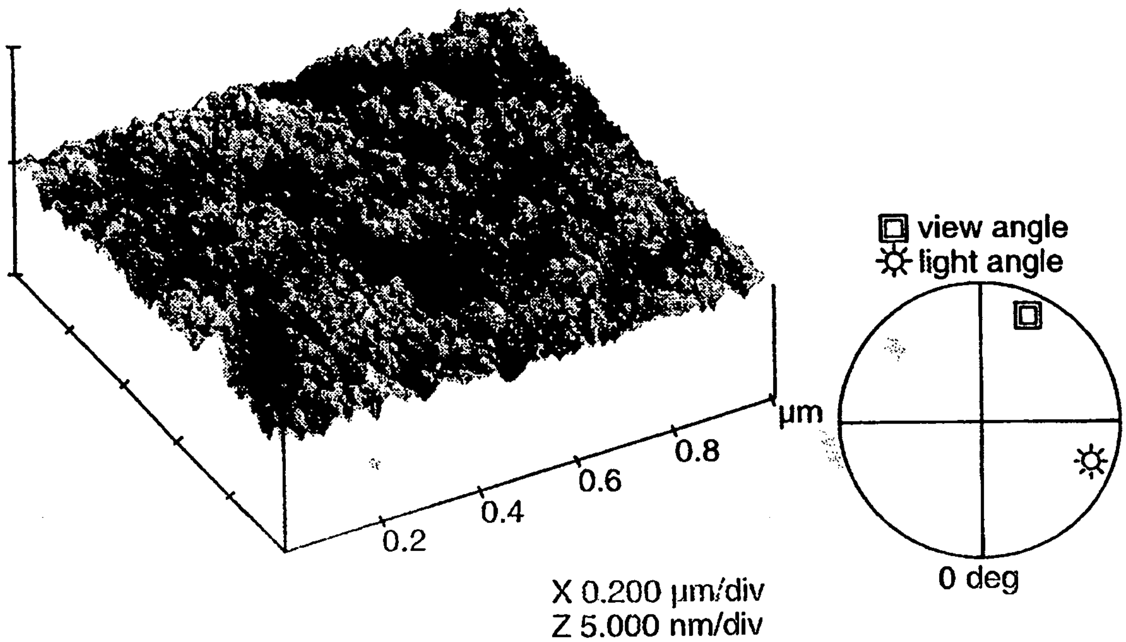
0.0 nm

Fig.9.


view angle
light angle
µm
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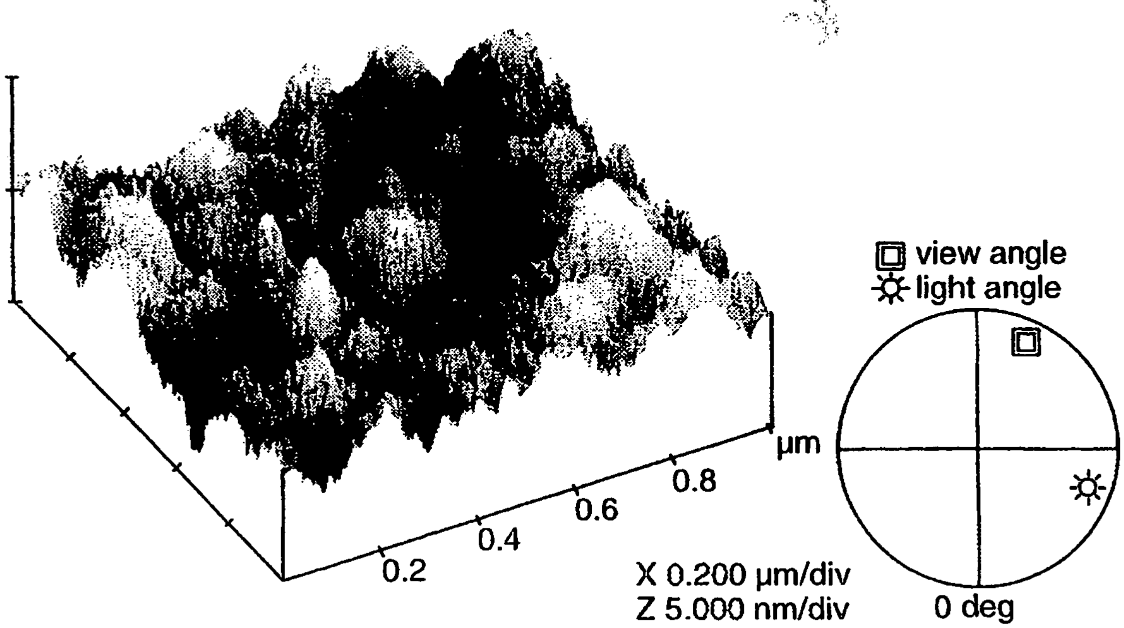
0.4
0.6
0.8
X 0.200 µm/div
Z 5.000 nm/div
0 deg

Fig.10.


view angle
light angle
µm
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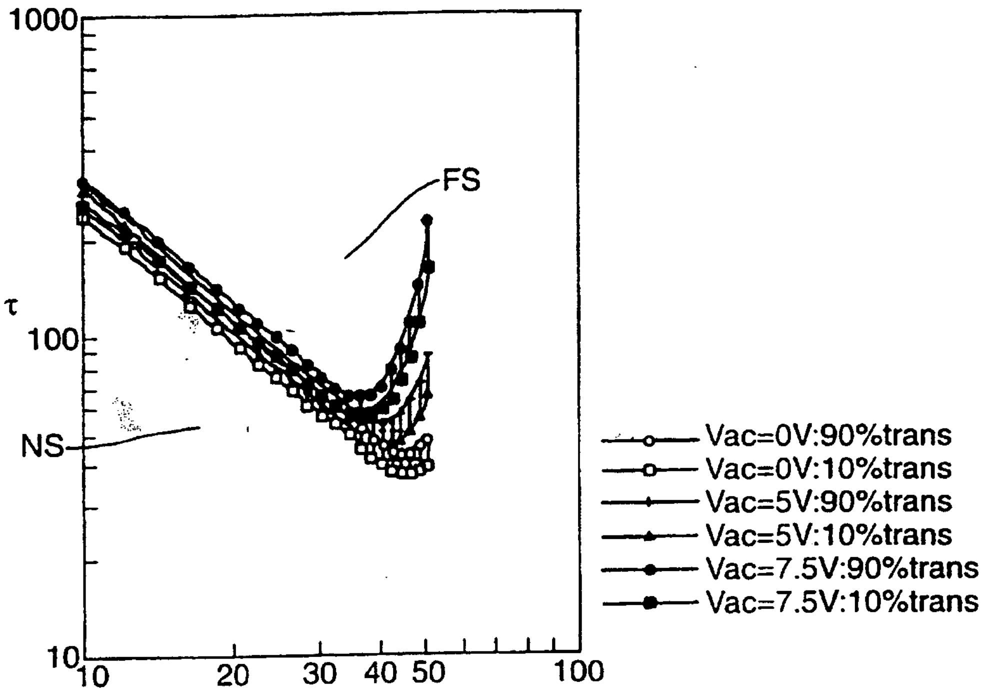
0.4
0.6
0.8
X 0.200 µm/div
Z 5.000 nm/div
0 deg

Fig.11.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100
10
τ
FS
NS
10
20
30
40
50
100
Vac=0V:90%trans
Vac=0V:10%trans
Vac=5V:90%trans
Vac=5V:10%trans
Vac=7.5V:90%trans
Vac=7.5V:10%trans

Fig.12.

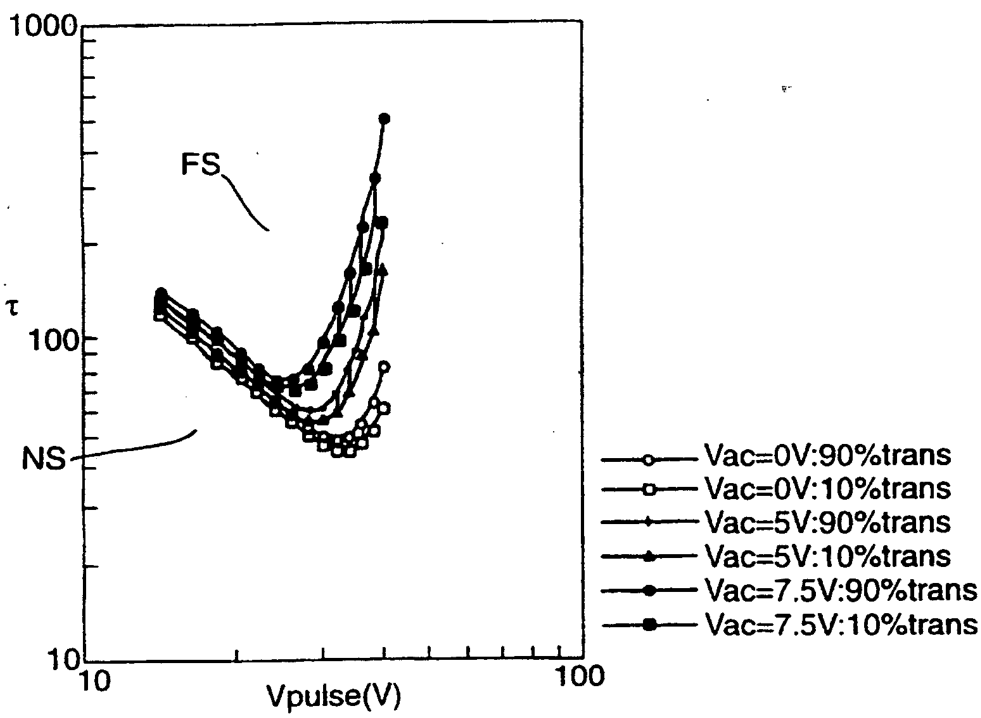
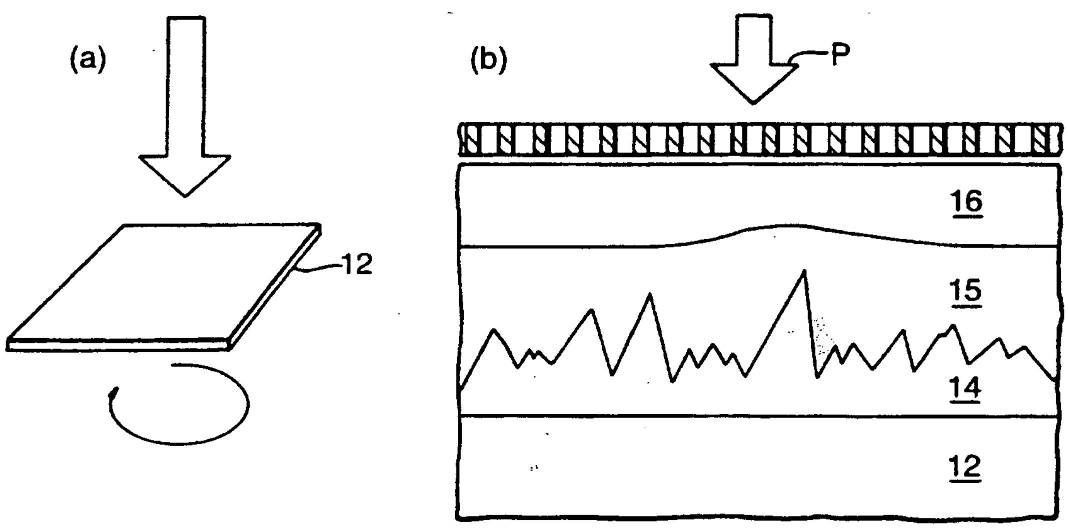

1000
100
10
τ
FS
NS
10
100
Vpulse(V)
Vac=0V:90%trans
Vac=0V:10%trans
Vac=5V:90%trans
Vac=5V:10%trans
Vac=7.5V:90%trans
Vac=7.5V:10%trans

Fig.13.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 97/01943

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02F1/1333 G02F1/141 G02F1/1337 G02F1/1343

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 595 219 A (SONY CORP) 4 May 1994 see page 6, line 7 - page 7, line 54 see page 11, line 54; figures 1-3,11; examples 1-5 ---	1,2,7,8, 10-17, 20,21
X	EP 0 584 963 A (CANON KK) 2 March 1994 see column 7, line 9 - column 15, line 28; figures 1-11 see figures 25,32-41; examples 61-6,11,13,15 see figures 53-56 --- -/--	1,3-5, 10-14, 16,18,19

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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1

Date of the actual completion of theinternational search	Date of mailing of the international search report
20 October 1997	29/10/1997
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Stang, I

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 861 143 A (YAMAZAKI SHUNPEI ET AL) 29 August 1989 see the whole document	1,2,11, 13,15
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 096 (P-1322), 10 March 1992 & JP 03 276126 A (MATSUSHITA ELECTRIC IND CO LTD), 6 December 1991, see abstract; figures 1-6	1,20,21
A	EP 0 240 010 A (CANON KK) 7 October 1987 see the whole document	1,17

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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PCT/GB 97/01943

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